CHAPTER 3

MATERIALS, PROPERTIES, STANDARD TESTS AND EFFLORESCENCE

3-1. Introduction. This chapter is an overview of the nature, properties and standard tests of the materials which are used for masonry construction. The material presented in this chapter is primarily concerned with the properties of clay and concrete masonry units which affect structural design. A discussion of the causes, methods of prevention and methods of cleaning of efflorescence is also included.

3-2. Clay masonry units.

a. Ingredients. Clay masonry units primarily consists of clay, shale or similar naturally occurring earthy substances, water and additives. Most clays are composed mainly of silica and alumina of extremely small particle size formed by decomposition of rocks.

b. Manufacturing processes. The majority of the solid and hollow clay masonry units currently used in the U.S. are produced by the "stiff-mud" process, also known as the "wire-cut" process. The basic components of the process are-preparation of the clay or clays; mixing with water, and additives if any; extrusion through a die as a continuous ribbon; cutting the clay ribbon into discrete units using steel wire; and controlled firing in which the units are heated to the early stage of incipient vitrification. Vitrification occurs when a material changes to a glassy substance by heat and fusion. Peak temperatures attained during the firing sequence are in the 2000-degree Fahrenheit range. Solid clay units, as defined below, may also be manufactured by molding processes, for example, the soft mud and dry press. Subsequent to molding, the units are dried and fired as in the wire-cut process.

c. Size and shape. Clay masonry units are available in a wide variety of shapes, sizes and coring patterns, several of which are illustrated in figure 3-1. Figures 3-la through 3-1e represent clay units defined as solid, that is, the net area is 75 percent or more of the gross area. Figure 3-1f illustrates a hollow unit. The width, W, of solid clay units normally ranges from 3 inches to 4 inches, the height, H, from 2¼ inches to 4 inches and the length, L, from 7⅝ inches to 11⅝ inches, although larger units have been produced. Hollow clay units whose net area is less than 75 percent of the gross area, as shown in figures 3-1f have been produced in a relatively small number of sizes and core configurations. The shape shown has a length equal to 11⅝ inches and a height equal to 3⅝ inches. Widths of 3⅝ inches, 5⅝ inches and 7⅝ inches are also available.

d. Visual properties. The color of clay masonry units by the chemical composition, surface treatment, burning intensity, and methods of burning control. These factors also affect the strength of units. The choice of color for aesthetic purposes

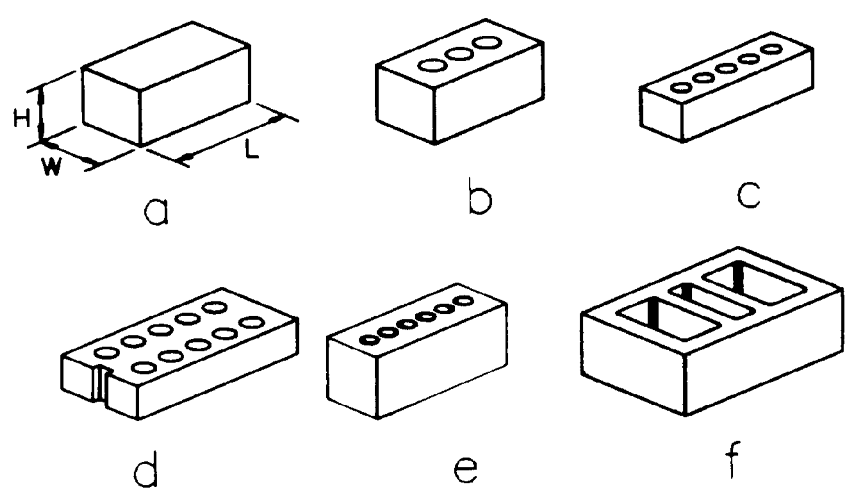

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Figure 3-1. Typical Clay Masonry Units.

thus may influence structural performance. Various types of surface texturing, which is formed by steel wire cutting parallel to the direction of extrusion, may be created on the face surfaces of clay units. Surface texture is a factor influencing bond strength between the clay units and the mortar or grout.

e. Material properties. Material properties of clay masonry units which can affect their structural performance include: durability, initial rate of absorption, compressive strength, flexural strength, and expansion potential.

(1) *Durability.* Durability primarily refers to the ability of a masonry unit to withstand environmental conditions, such as freeze-thaw action. Clay masonry units have been classified in ASTM C 62, C 216, and C 652 according to their weather resistant capacities into the following grades: Severe Weathering, SW; Moderate Weathering, MW; and No Weathering, NW. Durability, or weather resistance classification, is evaluated in terms of compressive strength and water absorption as presented in table 3-1.

Table 3-1. Durability[1]

	Minimum Comprehensive Strength (Brick Flatwise) Psi Gross Area		Maximum[2] Water Absorption by 5 hour Boiling percent		Maximum[3] Saturation Coefficient	
Designation	Average of 5 Bricks	Individual	Average of 5 Bricks	Individual	Average of 5 Bricks	Individual
SW	3000	2500	17.0	20.0	0.78	0.80
MW	2500	2200	22.0	25.0	0.88	0.90
NW[4]	1500	1250	No Limit	No Limit	No Limit	No Limit

[1]Summarized from ASTM C 62, C 216 and C 652

[2]Initially immersed for 24 hours in cold water. Five hour absorption equals the amount of water absorbed after immersion in boiling water for five hours expressed as a percentage of the weight of the dry unit.

[3]Saturation coefficient is the ratio of absorption after 24 hours in cold water to the absorption after 5 hours in boiling water.

[4]Applies only to a class of masonry units covered by ASTM C 62.

(2) *initial rate of absorption.* Clay masonry units have a tendency to draw water from mortar or grout with which they are in contact due to a capillary mechanism caused by small pores in the units. This phenomenon is termed the initial rate of absorption, IRA, or suction and has been linked to structural characteristics of masonry such as the bond between mortar and the unit. The quality of bond between mortar and masonry unit is a function of properties of each. However, for many often used mortar mixes an IRA value in the 10-25 grams per 30 square inches per minute range has been observed to be most desirable. Absorption test procedures can be found in ASTM C 67.

(3) *Compressive strength.* Compressive strength of clay masonry units is measured by loading specimens to failure in a direction consistent with the direction of service loading in accordance ASTM C 67. Compressive strength of units provides a basis for assuming the compressive strength of the masonry assemblage.

(4) *Flexural strength.* Flexural strength, or modulus of rupture, determined in accordance with ASTM C 67, is basically a measure of the tensile strength of a masonry unit. It is somewhat correlated to unit compressive strength.

(5) *Expansion potential.* Clay masonry units immediately after manufacture are extremely dry and expand due to absorption of moisture from the atmosphere. The magnitude of the initial expansion depends on the characteristics of the unit materials, the firing temperature and the ambient moisture conditions. The initial expansion is irreversible. Additional, but small, amounts of contraction or expansion due to temporary variations in masonry moisture content may occur. Clay unit masonry is also subject to expansion and contraction due to temperature variations.

3-3. Concrete masonry units. Concrete masonry units are made from lightweight or normal weight aggregates, or both, to obtain three classes of masonry units; normal weight, medium weight, and lightweight. The structural requirements of ASTM C 90 are the same for all classes. Normal weight units are generally used where lightweight aggregate is not readily available and the cost of obtaining the lightweight aggregate does not offset the advantages of lightweight units. The advantages of lightweight units include ease of handling and hauling, increased productivity, reduced dead loads, improved resistance to thermal flow, improved absorption of transmitted sound, and higher fire resistance. One disadvantage of lightweight units is that they are more porous. This makes them more difficult to paint or seal as required for interior and exterior exposure.

a. Ingredients. Concrete masonry units primarily consist of portland cement or blended cement, aggregate and water. Hydrated lime and/or pozzolans as well as air entraining agents may be used. Other ingredients that have been established as suitable for use in concrete such as coloring pigments, ground silica, etc., may also be used.

b. Manufacturing process. Concrete masonry units are cast using no slump concrete. The mixture is placed into molds and vibrated under pressure for a specified time to obtain compaction. Higher strength units can be obtained by subjecting the material to longer vibration and compaction periods. The units are removed from the molds and may be cured under normal atmospheric conditions, or by autoclaving (steam curing).

c. Size and shape. Concrete masonry units are available in a wide variety of sizes and shapes as shown in figure 3-2. They may be classified as hollow or solid.

(1) A solid unit is defined in ASTM C 90 as having a net area not less than 75 percent of the gross area. A type of unit known as concrete building brick, ASTM C 55, is available which is completely solid. Solid units are typically 7⅝ inches high and are available in several lengths and widths. Concrete bricks are normally 3⅝ inches wide, 2¼ inches high and 7⅝ inches or 15⅝ inches long.

(2) A hollow unit is defined in ASTM C 90 as having face shell and web thicknesses which conform to the requirements listed in Table 2 of the C 90 standard. Most hollow concrete masonry units range from 50 to 70 percent of the gross area, depending on such factors as: unit width, wall (face shell and web) thickness, and core shape. Hollow units are typically 15⅝ inches long; either 7⅝ inches or 3⅝ inches high; and 7⅝ inches, 5⅝ inches, or 3⅝ inches wide. Nominal widths up to 16 inches are also available in many areas. The walls of most hollow concrete units taper or are flared and thicker on one bed surface of the unit than the other to enable release from the mold during production. Hence, the net concrete cross-sectional area may be greater on the top of the unit than the bottom. For structural reasons, ASTM C 90 stipulates minimum wall thickness for load-bearing concrete masonry units.

d. Visual properties. Color other than the normal concrete gray may be obtained for concrete units by adding pigments into the mix at the time of manufacture or by painting after installation. A variety of surface effects are possible including smooth face, rough (split) face, and fluted, ribbed, recessed, angular and curved faces, some of which may affect cross-sectional area calculations.

e. Classifications. Concrete masonry units are classified according to moisture content requirements. The two types of moisture controlled units are:

(1) Type I, Moisture-Controlled Units, which must conform to the appropriate ASTM moisture content requirements.

(2) Type II, Nonmoisture-Controlled Units, which have no moisture control requirements.

f. Material properties. The material properties

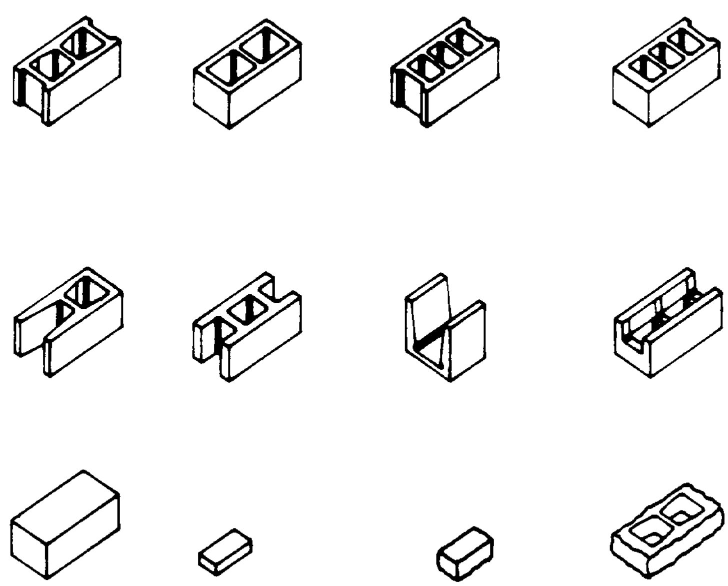

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Figure 3-2. Examples of concrete masonry units.

of concrete units which can affect the structural performance of installed masonry include: absorption; moisture content; shrinkage potential; temperature expansion/contraction; compressive strength; and flexural strength.

(1) *Absorption.* Absorption of a concrete masonry unit, determined in accordance with ASTM C 140 is the total amount of water, expressed in pounds per cubic foot, that a dry unit will absorb and is somewhat related to density.

(2) *Moisture content.* Moisture content is expressed as a percent of the total water absorption possible for a given concrete masonry unit. Dimensional changes of concrete masonry due to changes in unit moisture content can have serious effects upon the structure depending upon the nature of the boundary conditions and size of a given masonry element. The most common effect is shrinkage cracking due to a loss of moisture. Moisture loss is affected by the humidity of the air surrounding a particular masonry element. Moisture conditions, and thus cracking potential, may be significantly different for interior and exterior elements.

(3) *Shrinkage potential.* Shrinkage potential characteristics of a given unit, determined according to ASTM C 426, depend upon the method of manufacture and the materials. The linear shrinkage potential values given in the appropriate ASTM's represent an attempt to equalize drying shrinkage for units of different shrinkage potential considering differences in humidity conditions.

(4) *Temperature expansion/contraction.* As is the case for most materials, concrete masonry expands and contracts with temperature changes.

(5) *Compressive strength.* The compressive strength of concrete masonry units is established in accordance with ASTM C 140. This test is a measure of unit quality. The compressive strength of the masonry units, along with the mortar strength, provide the basis for assuming the compressive strength of the masonry assemblage. Factors which affect compressive strength include: water-cement ratio, degree of compaction, and cement content. Minimum compressive strength requirements are presented in the appropriate ASTM's for the various kinds of units.

(6) *Flexural strength.* Flexural strength, modulus of rupture, is basically a measure of the tensile strength of a masonry unit and is somewhat correlated to the unit compressive strength.

3-4. Mortar. Mortar, ASTM C 270, is a mixture of cementitious materials, aggregate and water. Mortar serves to bond masonry units together to form a composite structural material. As such, mortar is a factor in the compressive, sheer, and flexural strengths of the masonry assemblage. In addition, mortar compensates for dimensional and surface variations of masonry units, resists water and air penetration through masonry, and bonds to metal ties, anchors, and joint reinforcement so that they perform integrally with the masonry units.

a. Cementitious materials. Cementitious materials used are portland cement, ASTM C 150; or portland blast furnace cement, ASTM C 595; and lime, ASTM C 207; or masonry cement, ASTM C 91. Masonry cement has limited applications. Mortar made with portland cement, lime, aggregate (sand) and water is preferred since all constituents are well defined. While both types of mortar have similar attributes and requirements, the discussion herein applies specifically to mortar made with portland cement, lime, and aggregate. In general, it may not be possible to specify a mortar, which will be optimal for both workability and strength. A mortar which is workable with the masonry units being used under site environmental conditions will usually result in a masonry assemblage with acceptable strength and good quality joints.

b. Aggregate (sand). Well-graded sand, ASTM C 144, with a uniform distribution of particle sizes is necessary to produce a workable mortar which is dense and strong in the hardened state. Sand on the finer side of the permitted gradation range will produce a more workable mortar than a mortar made with coarser sand. However, the mortar with finer sand requires more water to be workable and is therefore weaker. The particles of manufactured sand are sharp and singular and tend to produce a less workable mortar than that made with natural sand of rounded particles. More water may be required to obtain adequate workability of mortar made with manufactured sand than that made with natural sand, resulting in a lower strength due to the higher water-cement ratio.

c. Mortar proportions. According to ASTM C 270, mortar may be specified either in terms of proportions (by volume of portland cement, hydrated lime, and aggregate) or in terms of properties (required compressive strength). The proportion method is the only method allowed by the guide specification. It should be noted that mortar conforming to the proportion specifications of ASTM C 270 may have compressive strength far in excess of the minimum values prescribed for the property method.

d. Mortar types. The four types of mortar given in ASTM C 270 are; in order of descending strength; M, 5, N, and 0. Generally as strength increases, workability decreases. Since a good mortar must have a combination of strength and workability, the mortars on the extremes (M and 0) should not be used. Although S and N are allowed in the guide specifications, Type S exhibits the best overall qualities of strength and workability and normally should be specified.

e. Water retentivity. Mortar exposed to air tends to lose water by evaporation. Mortar in contact with masonry units tends to lose water to the units because of the suction of the units. Retentivity is the mortar property associated with resistance to such water loss and resultant loss of workability. Lime in mortar improves the water retentivity and workability. Ideally, retentivity of a mortar should be compatible with the suction of the units used and environmental conditions, such as, temperature and humidity, so that adequate workability is maintained. Water content of mortar should be as high as possible consistent with proper workability and suction of the masonry units to maximize bond of the mortar to units. Water retentivity is measured by methods described in ASTM C 91. Units with high suction require the use of mortar with high retentivity to prevent excess and rapid water loss and reduced workability. It is noted in ASTM C 67, in the case of clay-unit masonry, that mortar which has stiffened due to water loss because of suction results in poor bond and water permeable joints. It is suggested in ASTM C 67 that clay masonry units with initial rates of absorption in excess of 30 grams per minute per 30 square inches be wetted prior to placing to reduce suction. If wetting is done, care should be taken to ensure uniformity.

f. Flow. Flow determined by methods of ASTM C 109 is a rough measurement of workability, but is not a test amenable to construction sites. No generally accepted procedure has been developed for field measurement of workability; the mason is the best judge.

g. Factors affecting mortar compressive strength. Mortar compressive strength, typically measured by uniaxial compression of 2 inch cubes in accordance with ASTM C 109 is a measure of relative mortar quality. Because of several factors, such as, state of stress, water content, and dimensions, the compressive strength of a mortar cube is not directly related to compressive strength of mortar in a masonry joint. The basic factors which affect uniaxial cube compressive strength, however, are essentially those which affect mortar performance in masonry, such as, proportions of portland cement, hydrated lime and sand, water content, admixtures, air content, mixing time, and sand characteristics. The proportions are critical factors affecting cube compressive strength. The variation in mortar cube strength due to mix proportions is illustrated in figure 3-3. The circled values for sand and lime illustrates a typical Type S mix of 1 part cement, ½ part lime and 4½ parts sand. The figure indicates that the expected cube strength is approximately 3700 pounds per square inch, using these proportions. The band between the two sloping straight lines reflects the range of proportions as prescribed in ASTM C 270.

h. Factors affecting mortar to unit bond. Because mortar not only seals masonry against wind and water penetration, but also binds masonry units together, strength and bond of mortar are essential to well-constructed masonry. Two forms of bond strength are important for structural purposes, tensile bond strength and shear bond strength. Tensile bond is required to resist forces perpendicular to a mortar-unit joint while sheer bond is required to resist forces parallel to such joints. The factors which affect bond are basically common to both with the exception of the influence of compression on shear bond. Factors affecting bond strength include:

(1) *Mortar properties.*

(a) Cement content. Other factors equal, greatest bond strength is associated with high cement content.

(b) Retentivity. Bond strength is enhanced if high retentivity mortar is used with high-suction units and low absorption.

(c) Flow. Bond is enhanced by using the maximum water content consistent with good workability considering unit properties and environmental conditions.

(d) Air content. Bond decreases with increasing air content.

(2) *Masonry unit properties.*

(a) Surface texture. Mortar flows into voids, cracks, and fissures and forms a mechanical attachment to the surface of the unit.

(b) Suction. For a given mortar, bond strength decreases as unit suction increases. This is perhaps due to the rapid loss of water to the unit on which mortar is placed. The mortar becomes less workable and bond becomes less reliable.

(3) *Workmanship factors.*

(a) Time. The time lapse between spreading mortar on a unit and placing a unit upon that mortar should be minimized to reduce the effects of water loss from mortar due to suction of the unit on which it is placed.

(b) Movement. Movement of units after placing can reduce, if not break, bond between mortar and unit.

(c) Pressure and tapping. Units must be placed on mortar with sufficient downward pres-

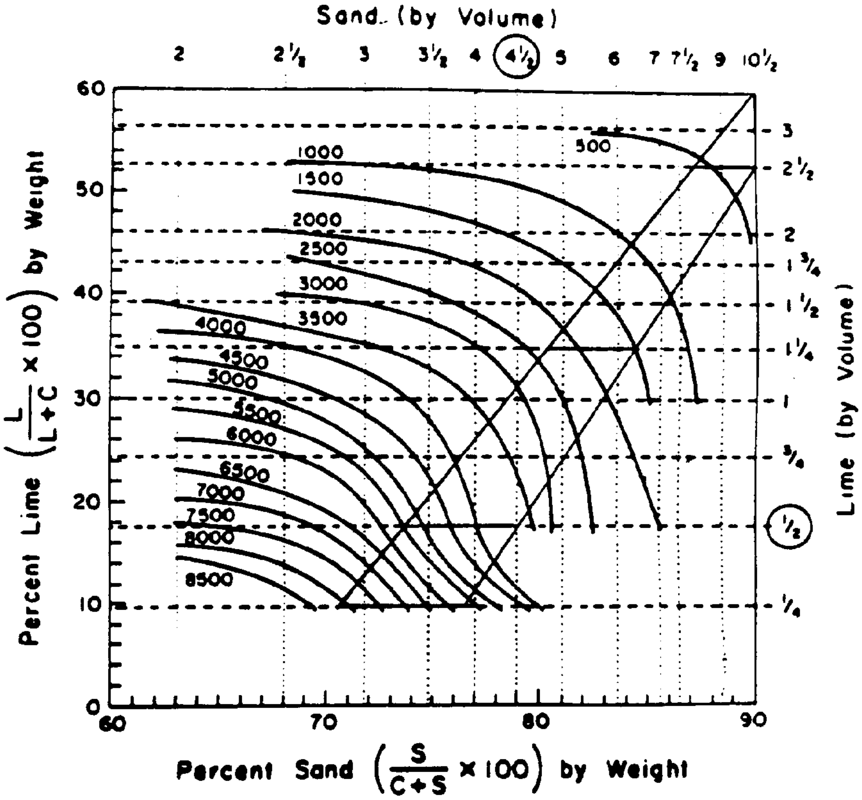

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Figure 3–3. Strength of mortar (psi) versus constituent proportions.

sure, possibly augmented by tapping, to force the mortar into intimate contact with the unit surface.

i. Construction factors effecting mortar. Proper mixing is essential to obtain a uniform distribution of materials and the desired workability and strength properties. Retempering, that is, adding water to mortar to restore workability as permitted by ASTM C 270 should be employed with extreme caution because the water-cement ratio may be altered with attendant loss of strength.

3-5. Grout. Grout, ASTM C 476, is a mixture of cementitious materials and aggregate to which sufficient water has been added to permit the grout to be readily poured into masonry grout spaces without segregation of the materials. Grout is placed in the cavities formed by the masonry units. It bonds to the masonry units and to steel reinforcement, ties, and anchors to form a unified composite structure.

a. Grout type and materials. Grout is identified as fine or coarse depending on the maximum size of the aggregate used. Fine or coarse grout should be used in accordance with the guide specification.

b. Grout strength. Grout will have a minimum compressive strength of 2000 pounds per square inch as measured by a uniaxial compressive test in accordance with ASTM C 1019.

c. Requirements during construction. Masonry units and grout interact in the same manner as unit-mortar interaction, that is, water is drawn from the grout into the masonry by suction. The final grout strength is a function of water content after suction.

(1) *Mixing grout.* Because of better control, grout should be batched and mixed in transit-mix trucks.

(2) *Placing grout.* Grout may be poured or pumped into grout spaces. Proper placement of grout requires that it be sufficiently fluid to be pourable and to completely fill the grout space. The suction of the masonry units, IRA, in the case of clay masonry units, will influence the amount of water required in grout. Higher water content is required if masonry units have a high rate of absorption (suction) to reduce the tendency of grout to adhere to the sides of the grout space while it is being poured and thus constrict the space. The converse is true if the units have low suction. A grouting admixture may be useful in retarding water loss from grout. The water content may be lower for large grout spaces (4-inch least dimension), than for small grout spaces (2-inch or smaller least dimension). Slump, as measured by

the standard 12 inch truncated cone test, is typically from 8 inches to 10 inches, depending upon the fluidity required.

(3) *Consolidating grout.* Consolidation is essential to obtaining grout in-place without voids or debonding due to shrinkage. Poor consolidation may cause reduced masonry compressive strength and poor bond of grout to masonry unit. Mechanical vibration is greatly superior to puddling and should be used for consolidating all grout pours greater than one masonry course in height. Consolidation should be done by vibrating soon after grout placement and by re-vibrating when the excess water has been absorbed from the grout by the masonry units. Mechanical vibration must be done before the grout has stiffened to prevent a void in the grout caused by the vibrator.

3-6. Reinforcement. Masonry is reinforced with steel bars or joint reinforcement. Joint reinforcement, placed in mortar beds, is unique to masonry and is primarily used to resist internal forces due to shrinkage or thermally-induced movement.

3-7. Standard tests.

a. Compression. The compressive strengths of masonry assemblages may be established by testing small masonry assemblages referred to as "prisms", in accordance with ASTM E 447. To establish the compressive strength of a given unit-mortar assemblage, a minimum of three prisms must be tested. Prisms may be constructed in stack-bond or in a bonding arrangement which simulates the bonding pattern to be used in the structure, except no structural reinforcement is used in the prisms. Masonry prisms should be constructed with the same materials, joint thickness, and workmanship used in the structure.

b. Shear. In reinforced masonry, shear loads may be carried either by the masonry or, if the masonry is not adequate, by the reinforcing steel. Masonry is an assemblage of discrete units and mortar, so when the shear force is carried by the masonry, two forms of shear strength exist. These strengths are diagonal tension strength and sliding shear strength along the mortar joint. The standard tests used to determine the shear strength in masonry are as follows:

(1) *Diagonal tension tests.*

(a) The standard diagonal tension test; presented in ASTM E 519, Diagonal Tension (Shear) in Masonry Assemblages; establishes the diagonal tension of masonry panels by loading 4-foot by 4-foot panels in compression along one diagonal. Failure occurs in tension perpendicular to the diagonal. The value of the compression load, P, at failure is converted to an equivalent shear stress, S_s, by:

$$S_s = \frac{0.707P}{A} \qquad \text{(eq 3-1)}$$

Where:

A = The average of the gross areas (solid-unit masonry) or net areas (hollow unit masonry) of the two contiguous upper sides of the specimen.

(b) The racking test described in ASTM E 72 (Section 14) has been used to measure diagonal tensile strength of eight foot by eight foot wall specimens. However, hold-down forces induced by the test fixture complicate the state of stress.

(2) *Sliding shear strength.* The sliding shear strength is the strength in bond between the mortar and the units which resists relative movement of adjacent units in a direction parallel to the mortar joint between them. In case of shear walls, where shear is normally considered to be a horizontal force parallel to the bed joints, sufficient bond between mortar and units must exist in order for diagonal tension strength to be developed. Otherwise failure occurs in step-wise fashion along a diagonal in the plane of the wall. It has been shown experimentally that joint shear strength is increased by compression across the joint. Results obtained by testing small specimens under controlled conditions reflect a friction coefficient of approximately 1.0.

c. Flexure test. The standard test to establish flexural strength in masonry is given in ASTM E 518, which provides requirements for materials, specimen preparation and configuration, testing, and calculations. The test establishes flexural tensile bond strength in a direction perpendicular to the bed joint by third-point or uniform loading of stack-bond specimens. Extreme care is required in handling flexural bond test specimens. Flexural tensile bond strength may also be determined by the "bond wrench" test. The test is based upon "prying off" one masonry unit at a time from a multi-unit stack-bond prism (or beam). Flexural tensile stress is calculated based upon an assumption of a linear flexural stress distribution across the unit width. Equations provided in ASTM C 1072 account for the effects of compression due to the load and its eccentricity. The test apparatus is detailed in the standard. Whereas flexural beam tests provide one data point, that is the beams fail at one joint, the bond wrench method provides as many data points as there are joints in the specimens.

(1) The flexural capacity of unreinforced masonry walls depends either upon the tensile bond between units, as shown in figure 3-4a, or upon the

shear-bond of overlapping units depending on the direction of flexure and type of construction as depicted in figure 3-4b. Flexure which induces shear-bond stresses between overlapping units may be limited by shear bond strength or by flexural tensile unit strength.

(2) The flexural capacity of reinforced masonry is essentially limited by masonry compressive strength or by tensile strength of the reinforcement. Compression reinforcement can add to flexural strength in beams, particularly if it is confined. Vertical reinforcement in shear walls is used to provide tensile strength for in-plane and out-of-plane reversible moment. Failure of slender shear walls in in-plane flexure is characterized by progressive damage to the masonry at the compression face followed by buckling of the unconfined vertical reinforcement. Confinement of vertical reinforcement in shear walls retards progressive damage and increases ductility.

(3) Tests of prisms and short walls under eccentric compression indicate that at failure the maximum compressive stress, due to combined bending and compression, calculated on the assumption of linear elastic behavior, exceeds ultimate uniaxial compressive stress, by a factor on the order of 4/3.

d. Modulus of elasticity. The modulus of elasticity of masonry, E_m, may be obtained by instrumenting compression specimens, prisms, in accordance with ASTM E 111. Experimental evidence indicates that moduli obtained from tests of flat-end prisms corresponds well to moduli of full-scale walls. Although the true stress-strain relationship of masonry is non-linear (basically a parabolic curve), in many applications it is possible that dead load stress is sufficient to achieve the initial stiffening represented by the lower portion of the curve of figure 3-5, thus justifying use of the inner portion which is often approximately linear. The design methods in this manual assumes E_m is linear and is assumed to change linearly with the compressive strength of masonry, Pm, as follows:

$$E_m = 1000\, f'_m < 3\,000{,}000 \text{ psi} \qquad \text{(eq 3-2)}$$

3-8. Efflorescence. Efflorescence is a fine, white, powdery deposit of water-soluble salts on the surface of masonry or in the pores of masonry. The most common salts are sulfate and carbonate compounds of sodium, potassium, calcium, magnesium and aluminum, although others exist.

a. Effect. The primary effect or objection is the appearance of efflorescence on the surface of masonry, both clay and concrete. It can be a serious visual defect. However, under certain conditions, salts deposited below the surface of a masonry unit can cause cracking and spalling due to forces generated by salt crystallization. This can further degrade appearance, but has the more serious effect of reduced structural properties.

b. Source. The main source of salts is the portland cement used in mortar and grout. Other sources can include the masonry units, sand used in mortar and grout, and the water. Hydrated lime used in mortar does not generally contribute to efflorescence.

c. Cause. Water-soluble salts are brought to the surface of masonry in solutions of water and deposited there by evaporation. The salts solution may migrate across the surfaces of the units or through the pore structure of the masonry units. Therefore, the conditions which lead to efflorescence are:

(1) A source of soluble salts must be present.

(2) A source of water to dissolve the salts must be available.

(3) The water must be in contact with the salts for a sufficient time to dissolve them and carry the solution to the masonry unit surface and into the pores of the units.

d. Control. Because the salts must be in solution

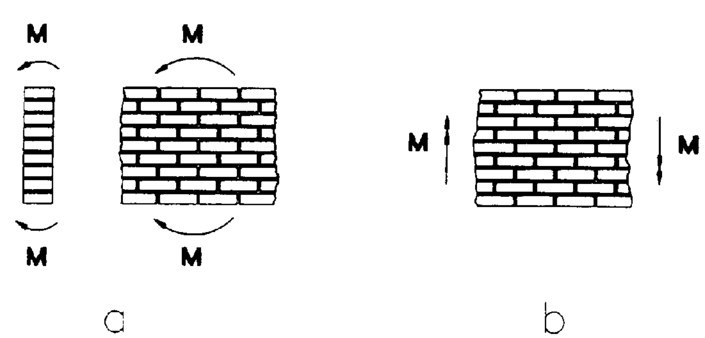

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Figure 3-4. Masonry wall flexure.

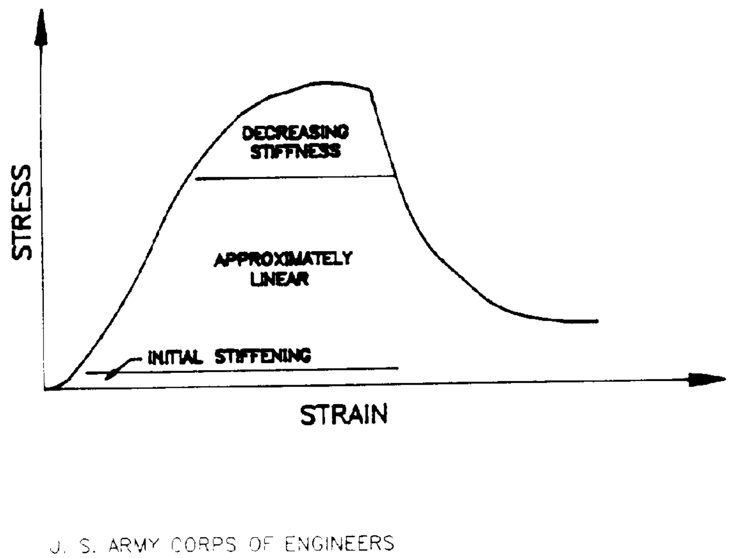

Figure 3–5. Masonry stress-strain curve.

to cause efflorescence, the obvious solution is to prevent the intrusion of water. This is difficult during construction because of the water present in mortar and grout. During construction, partially completed masonry elements and all on site masonry materials should be protected to minimize water intrusion from rain, snow or other sources.

e. Design Details. The most critical item in preventing efflorescence is providing good masonry details that will prevent water penetration into the completed masonry construction. The design and details of the structure, of which the masonry components are a part, should be such that water exposure and penetration of the masonry will be minimal. Overhanging eaves, capping of walls, copings, sealants, flashing, and tooling of mortar joints are examples. Equally important is the maintenance of these features.

f. Cleaning. Efflorescence occurring during or just after construction may disappear with normal weathering. If not, the following cleaning methods may be done in ascending order-doing the least necessary to achieve the desired result.

(1) Dry brushing may remove most efflorescence.

(2) In warm, dry weather washing may be used, but it should be realized that washing requires the use of water which may bring more salts to the surface.

(3) Chemical cleaners are available such as a 1:12 muriatic acid solution. Use requires presoaking to limit the depth of penetration of the solution and thorough washing afterwards to remove all traces of the solution.

(4) Sandblasting has been used but is not recommended because of its damaging effect on mortar and unit surfaces.